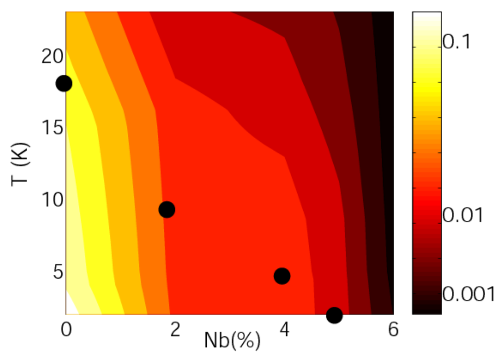
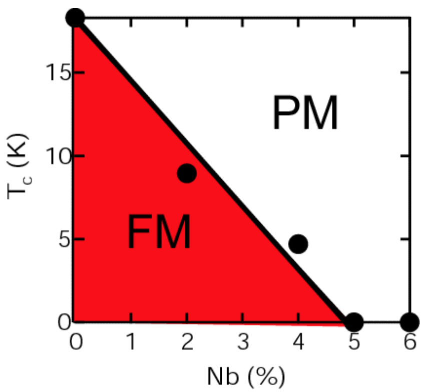
# Stability of Quantum Critical Ferromagnets

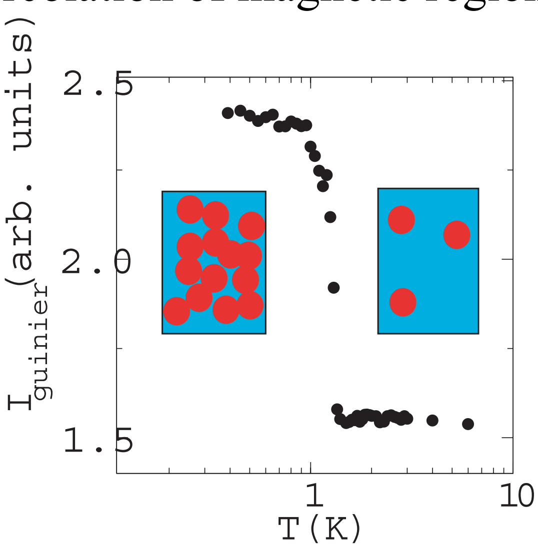
M. C. Aronson, University of Michigan, DMR-0405961

- Ferromagnetic $ZrZn_2$: Suppress magnetic moment and ferromagnetic onset temperature to zero by substituting Nb for 5% of Zr atoms.




- Pure $ZrZn_2$: continuous transition
  $Zr_{0.95}Nb_{0.05}Zn_2$: discontinuous transition, percolation of magnetic regions

Ferromagnets, materials such as iron which can generate their own magnetic fields, are of great importance for applications such as magnetic data storage and recovery, for electrical motors, for advanced sensors, and for medical applications such as imaging. Our research seeks to understand what physical factors control the temperature at which materials become ferromagnetic, and what the properties of materials are just as ferromagnetism sets in. We have been studying ZrZn2 as a model system. Our first objective is to demonstrate that we can control the size of the field which is created by ZrZn2 and the temperature at which it first occurs by modifying the composition of ZrZn2 by substituting Nb for a few percent of the Zr atoms. The plot at the upper right shows that the field is reduced either by raising the temperature or by adding Nb, although the latter is a much stronger effect. The onset temperature for ferromagnetism is shown at the upper right, showing that ferromagnetism is only possible for Nb concentrations less than 5%. We also want to understand how ZrZn2 becomes ferromagnetic, as the temperature is lowered from above the onset temperature to below. Neutron scattering is a very sensitive way to detect the internal structure of materials, and in particular to explore how the ferromagnetic field develops. We performed our experiments using the NG3 spectrometer at the National Center for Neutron Research at the National Institute for Standards and Technology, shown at the lower left. The plot at the bottom right shows that this field appears very suddenly, over a temperature span of less than 0.05 K. As depicted in the insets, above the onset temperature, magnetic fields are generated in small regions of the sample (red), which is mostly nonmagnetic. At the onset temperature, there is an explosive growth of these magnetic regions, which now occupy most of the sample volume, and together generate a magnetic field which is large enough to be detected outside the sample. This scenario for the onset of ferromagnetism is very like the process by which water droplets in steam condense into liquid water when the temperature is lowered, and it is possible that the sudden nature of the transition could be exploited for sensor applications, especially if it occurs at a useful operating temperature, i.e. near room temperature.

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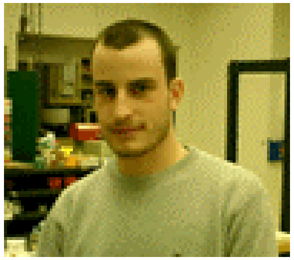


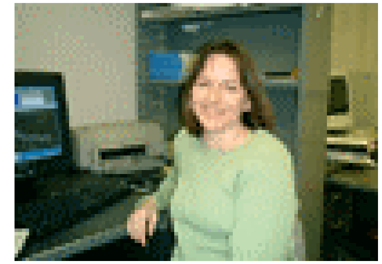

University of Michigan undergraduates William Gannon (left) and Tony Smith (right). Tony is a senior this year, and is applying to graduate programs in applied physics while pursuing a senior thesis in our group. Billy is beginning his junior year and will continue working with our group.

Postdoc Dmitriy Sokolov (left) and research scientist Sue Inderhees (right). Dmitriy is synthesizing new bulk materials with novel magnetic properties, and is carrying out neutron scattering measurements on them at the National Institute for Standards and Technology and Oak Ridge National Laboratory, and hopes as a future faculty member to be a core user of the Spallation Neutron Source, currently under construction in Oak Ridge. Sue Inderhees received her Ph.D in 1990, and is returning to research after raising two children. Sue's research centers on materials synthesis, using electron microscopy and scanning probe microscopies, as well as small angle neutron scattering to study large scale structures.

## Societal impact:

Our work seeks to explicate the generic factors which determine the temperatures at which materials become ferromagnetic, generating magnetic fields which can be used for applications as diverse as magnetic data storage and recovery, electrical motors, and advanced sensors, including novel magnetic stains and probes for medical use. This understanding is used to guide the rational synthesis of new materials, with enhanced properties, especially at the onset of ferromagnetism.